ARCHITECTURE 324
Structures II

Recitation 10

Sections 04&05

Instructor
Peter von Buelow

GSI
Alireza Fazel
March 27, 2025

Office Hours

→ Office Hours

→ Day: Fridays, 12:00 PM - 1:00 PM

→ Location Options:

- In-person meetings: [2223B]
- Virtual meetings via Zoom

Please make sure to sign up at least 24 hours in advance to allow for proper scheduling via this link:

https://docs.google.com/forms/d/e/1FAIpQLSdOb4gAc6SoCdsMAZP4zKrn3ecPyGt6dwVahVcOD3EqXGG-oA/viewform?usp=dialog

If the slots are fully booked or if you have a time conflict, please email me directly to find an alternative time (arfazel@umich.edu)

Contents

Tower test results

Frank's Tower of Power

Frank Michael, Jack Barbour, Nicholas Londono, Ravi Kumar

Load **210** lbs.

Weight **2.84** oz.

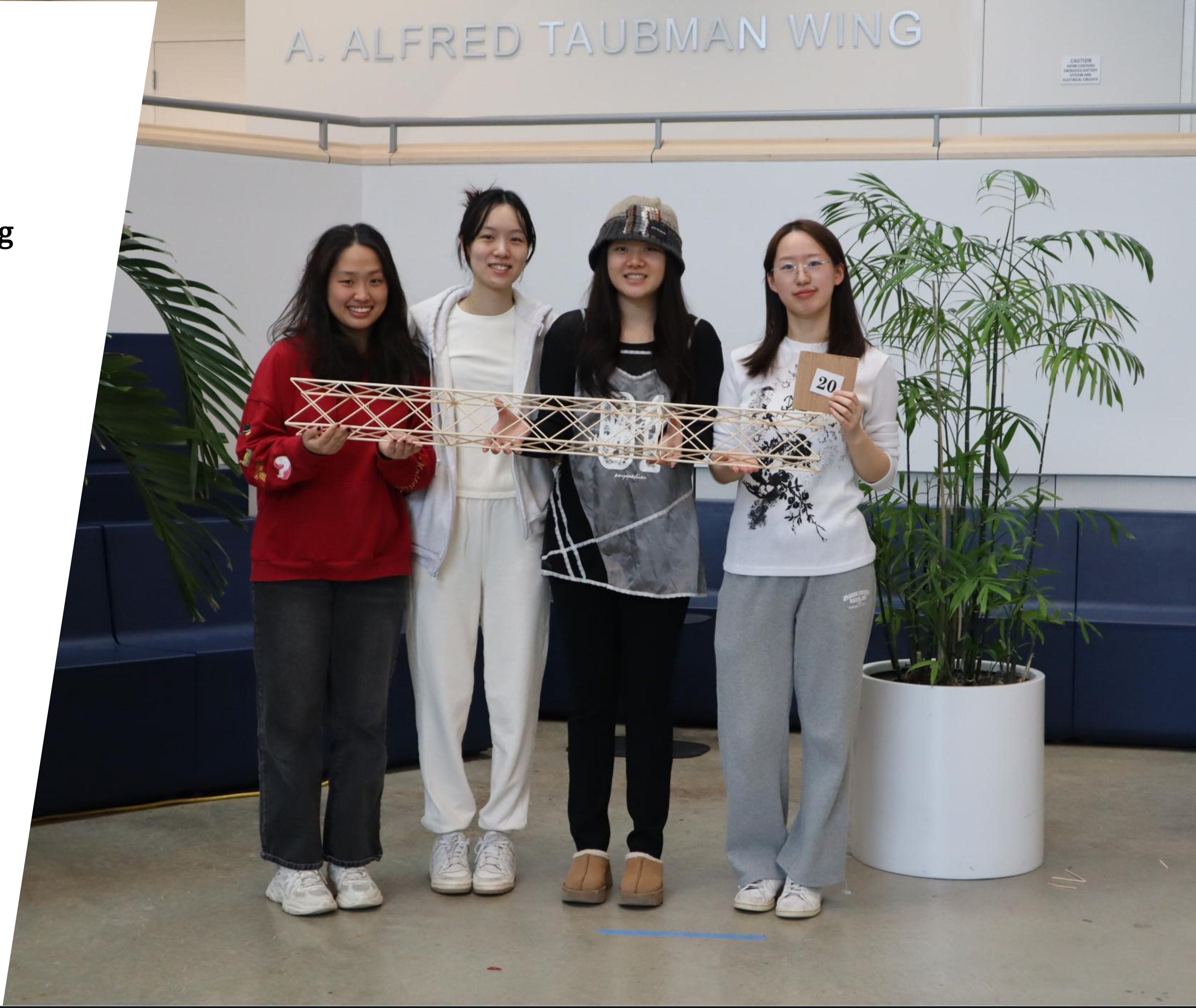
Tower test results

Tower in Power

Xiandong Lin, Ming Chen, Wanyi Lou, Yiduo Wang

Load **280** lbs.

Weight **3.99** oz.



Tower test results

Tipothy (Tippy)

Andrea Pesce, Kelci Coy, Shreya Sampath, Nicholas Pettigrew

Load **240** lbs.

Weight **3.86** oz.

Beam design

Rectangular Beam Design

Two approaches:

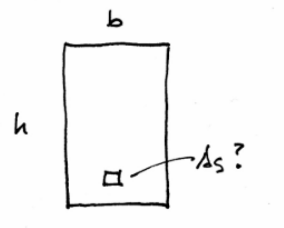
Method 1:

Data:

- Load and Span
- Material properties – f'_c, f_y
- All section dimensions: h and b

Required:

- Steel area – A_s



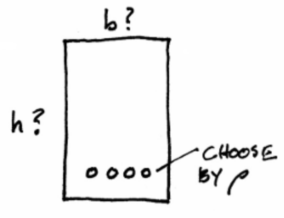
Method 2:

Data:

- Load and Span
- Some section dimensions – h or b
- Material properties – f'_c, f_y
- Choose ρ

Required:

- Steel area – A_s
- Beam dimensions – b or h



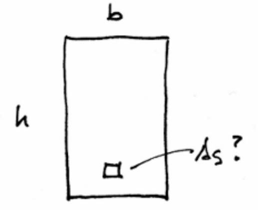
Rectangular Beam Design – **Method 1**

Data:

- Load and Span
- Material properties – f'_c, f_y
- All section dimensions – b and h

Required:

- Steel area - A_s



1. Calculate the factored load and find factored required moment, M_u
2. Find d = h – cover – stirrup – $d_b/2$
3. Estimate moment arm z = jd, for beams $j \approx 0.9$ for slabs $j \approx 0.95$
4. Estimate A_s based on estimate of jd.
5. Use As to find a
6. Use a to find A_s (repeat…until **2%** accuracy)
7. Choose bars for A_s and check A_s max & min
8. Check that $\varepsilon_t \geq 0.005$
9. Check $M_u \leq \phi M_n$ (final condition)
10. Design shear reinforcement (stirrups)
11. Check deflection, crack control, rebar development length

$$M_u = \frac{(\gamma_{DL} w_{DL} + \gamma_{LL} w_{LL}) l^2}{8}$$

$$A_s = \frac{M_u}{\varphi f_y \left(d - \frac{a}{2}\right)}$$

$$a = \frac{A_s f_y}{0.85 f'_c b}$$

$$M_n = A_s f_y \left(d - \frac{a}{2}\right)$$

Beam design

One-way Slab Design
Method 1

Data:
- Load and Span
- Material properties – f'_c, f_y
- All section dimensions:
- h (based on deflection limit)
- b = typical 12” width

Required:
- Steel area – A_s

First estimate the slab thickness, h.

Try first the recommended minimum.

Deeper sections require less steel, but of course more concrete.

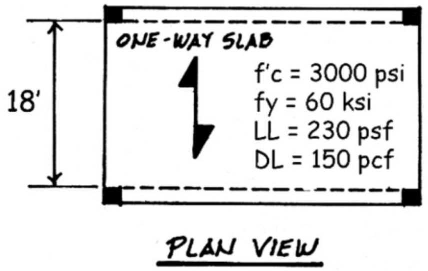


Table 7.3.1.1—Minimum thickness of solid nonprestressed one-way slabs

Support condition	Minimum h[1]
Simply supported	$\ell/20$
One end continuous	$\ell/24$
Both ends continuous	$\ell/28$
Cantilever	$\ell/10$

THICKNESS, h, BASED ON DEFLECTION

$h = \ell/20 = \frac{18 \times 12}{20} = 10.8''$ USE 11"

Rectangular Beam Design – **Method 2**

Data:
- Load and Span
- Some section dimensions – b or h
- Material properties – f'_c, f_y

Required:
- Steel area - A_s
- Beam dimensions – b and h

1. Estimate the dead load (estimate h and b) (L/8 ≤ h ≤ L/21, h ≈ L/12 and b:h ≈ 1:2 to 2:3), find M_u
2. Choose ρ (equation assumes ε_t = 0.0075)
3. Calculate bd^2
4. Choose b and solve for d (or d and solve b)
5. Revise h, weight, M_u, and bd^2
6. Find $A_s = \rho bd$
7. Choose bars for A_s, determine spacing and cover, and revise d
8. Check that $\varepsilon_t \geq 0.005$ (if not, increase h and reduce A_s)
9. Design shear reinforcement (stirrups)
10. Check deflection, crack control, steel development length

$$M_u = \frac{(\gamma_{DL} w_{DL} + \gamma_{LL} w_{LL}) l^2}{8}$$

$$\rho = \frac{\beta_1 f'_c}{4 f_y}$$

$$bd^2 = \frac{M_u}{\varphi \rho f_y \left(1 - 0.59 \rho (fy/f'_c)\right)}$$

$$A_s = \rho bd$$

$$a = \frac{\rho f_y d}{0.85 f'_c}$$

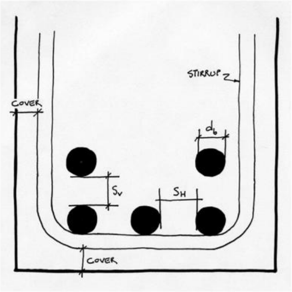
Beam design

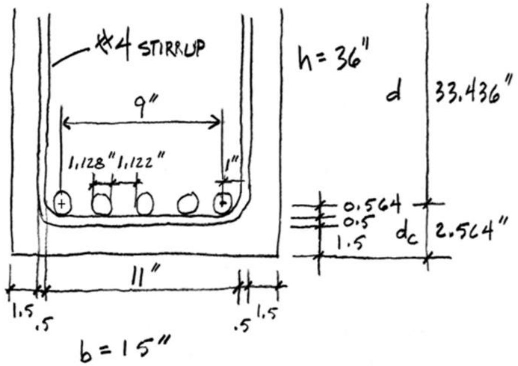
Rectangular Beam Design

7. Choose bars for A_s, determine spacing and cover, and revise d

CHOOSE BARS (SEE TABLE A.4)

TRY 5 x #9 BARS $A_s = 5.0 \text{ in}^2$





If bars do not fit in one layer, d is measured to the centroid of the pattern.

$$\bar{x} = \frac{\sum \mathbf{A} \times d_x}{\sum \mathbf{A}}$$

Table A.4 Areas of Groups of StandardBars (in.^{2})

Bar No.	Number of Bars: 2	3	4	5	6	7	8	9	10	11	12	13	14
4	0.39	0.58	0.78	0.98	1.18	1.37	1.57	1.77	1.96	2.16	2.36	2.55	2.75
5	0.61	0.91	1.23	1.53	1.84	2.15	2.45	2.76	3.07	3.37	3.68	3.99	4.30
6	0.88	1.32	1.77	2.21	2.65	3.09	3.53	3.98	4.42	4.86	5.30	5.74	6.19
7	1.20	1.80	2.41	3.01	3.61	4.21	4.81	5.41	6.01	6.61	7.22	7.82	8.42
8	1.57	2.35	3.14	3.93	4.71	5.50	6.28	7.07	7.85	8.64	9.43	10.21	11.00
9	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00
10	2.53	3.79	5.06	6.33	7.59	8.86	10.12	11.39	12.66	13.92	15.19	16.45	17.72
11	3.12	4.68	6.25	7.81	9.37	10.94	12.50	14.06	15.62	17.19	18.75	20.31	21.87
14	4.50	6.75	9.00	11.25	13.50	15.75	18.00	20.25	22.50	24.75	27.00	29.25	31.50
18	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00	40.00	44.00	48.00	52.00	56.00

Jack C McCormac, 1978
Design of Reinforced Concrete,

Rectangular Beam Design

7. Choose bars for A_s and determine spacing and cover, recheck h and weight

$d = 33.436"$

$$a = \frac{A_s f_y}{.85 f'_c\, b} = \frac{5(60)}{.85(3)15} = 7.843"$$

Make final check of M_n using final d, and check that $M_u \le \phi M_n$

$$M_n = A_s f_y \left(d - \frac{a}{2}\right) = 5(60)\left(33.436 - \frac{7.843}{2}\right)$$

$M_n = 8854$ K-" $= 737.8$ K-'

$\phi M_n = 0.9(737.8) = 664$ K-'

$M_u = 653.3 < 664$ ✓ ok

8. Check that $\varepsilon_t \ge 0.005$ (if not, increase h and reduce A_s)

$$c = \frac{a}{\beta_1} = \frac{7.843"}{0.85} = 9.227"$$

$$\epsilon_t = \frac{d - c}{c}(0.003)$$

$$\epsilon_t = \frac{33.436 - 9.227}{9.227}(0.003)$$

$\epsilon_t = 0.00787 > 0.005$ ✓ ok

9. Design shear reinforcement (stirrups)
10. Check deflection, crack control, steel development length

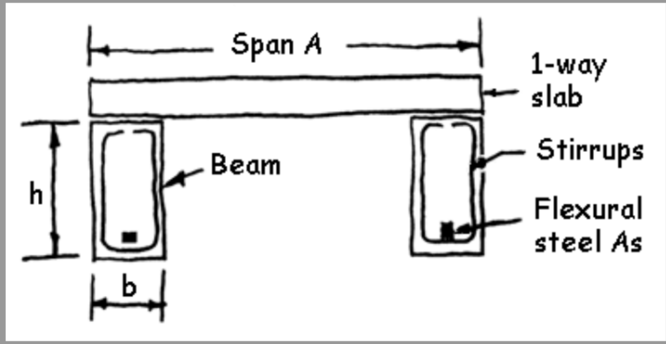
Problem Set 09

9. Concrete Beam Design

Using the Ultimate Strength Method, analyze the given section to determine its safe moment capacity, Mu, based on the given parameters. Check that the section is tension controlled (epsilon_t > 0.005), and that the amount of steel, As is more than the minimum, As_min.

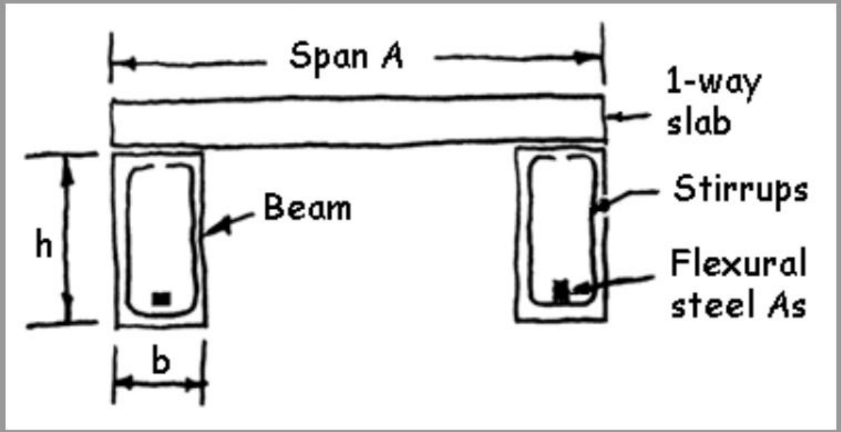
DATASET: 1 -2- -3-

Span of slab	14 FT
Span of beam	23 FT
Thickness of slab	9 IN
section width, b	10 IN
section height, h	18 IN
max. aggrigate size	0.75 IN
bar size number	8
stirrup bar size number	4
concrete cover	1.5 IN
concrete ultimate strength, f'c	5500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	55 PSF



Problem Set 09

#Q1: Unfactored dead load on beam from slab
#Q2: Unfactored dead load on beam from the beam (beam selfweight)



DATASET: 1 | -2- | -3-

Span of slab	14 FT
Span of beam	23 FT
Thickness of slab	9 IN
section width, b	10 IN
section height, h	18 IN
max. aggrigate size	0.75 IN
bar size number	8
stirrup bar size number	4
concrete cover	1.5 IN
concrete ultimate strength, f'c	5500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	55 PSF

$$\boldsymbol{DL_{slab}} = \boldsymbol{\rho} \times \boldsymbol{V} = 150\frac{lb}{Ft^3} \times \frac{14}{2}\ FT \times 9\ IN \times \frac{1\ FT}{12\ IN} \times 1\ FT = \mathbf{787.5\ PLF}$$

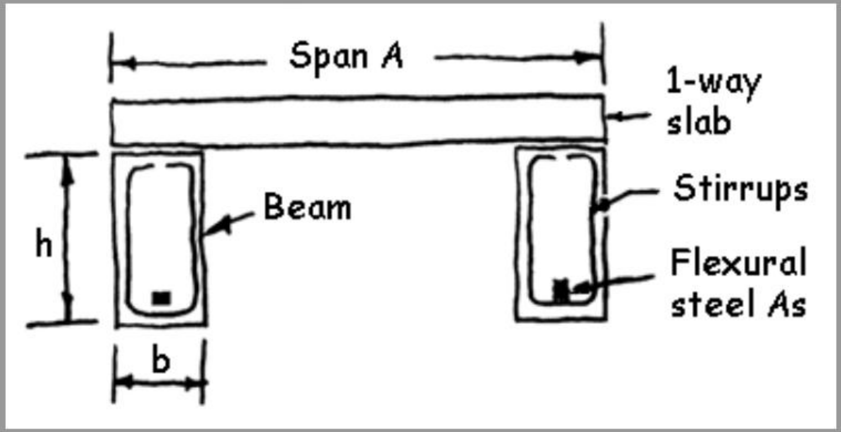
$$\boldsymbol{DL_{beam}} = \boldsymbol{\rho} \times \boldsymbol{V} = 150\frac{lb}{Ft^3} \times 10\ IN \times \frac{1\ FT}{12\ IN} \times 18\ IN \times \frac{1\ FT}{12\ IN} = \mathbf{187.5\ PLF}$$

Problem Set 09

#Q3: Unfactored live load on beam, LL
#Q4: Total factored beam load, wu

DATASET: 1 -2- -3-

Span of slab	14 FT
Span of beam	23 FT
Thickness of slab	9 IN
section width, b	10 IN
section height, h	18 IN
max. aggrigate size	0.75 IN
bar size number	8
stirrup bar size number	4
concrete cover	1.5 IN
concrete ultimate strength, f'c	5500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	55 PSF



$$LL_{beam} = \boldsymbol{Floor\ LL\ \times Tributary\ length} = 55\ PSF\ \times \frac{14}{2} = \mathbf{385\ PLF}$$

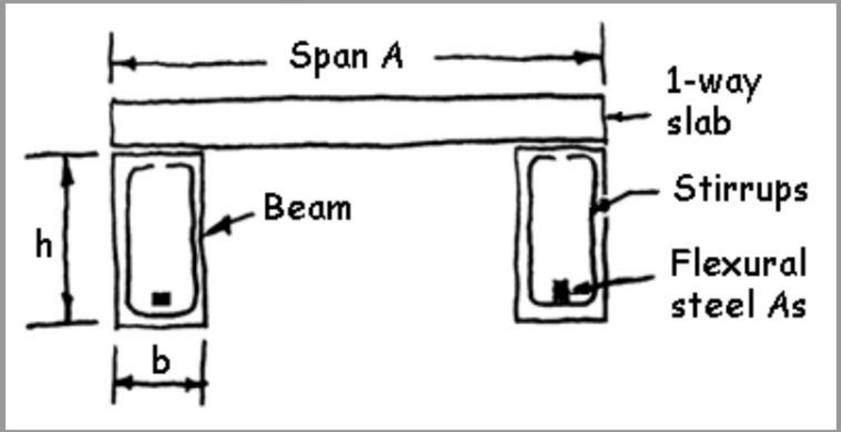
$$w_u = \mathbf{1.2\ DL + 1.6\ LL} = 1.2(787.5 + 187.5) + 1.6(385) = \mathbf{1786\ PLF}$$

Problem Set 09

#Q5: Factored design moment from the loads, Mu

DATASET: 1 -2- -3-

Span of slab	14 FT
Span of beam	23 FT
Thickness of slab	9 IN
section width, b	10 IN
section height, h	18 IN
max. aggrigate size	0.75 IN
bar size number	8
stirrup bar size number	4
concrete cover	1.5 IN
concrete ultimate strength, f'c	5500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	55 PSF



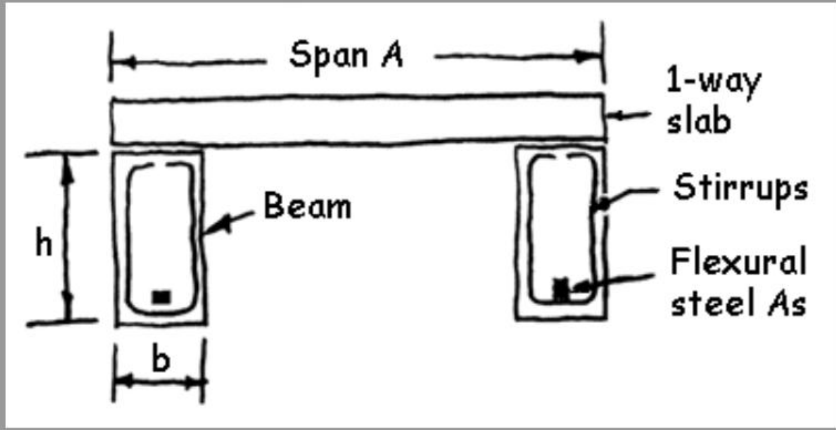
$$M_u = \frac{w_u\,L^2}{8} = \frac{1786\,(23)^2}{8} \times \frac{1}{1000} = 118.09\ K - FT$$

Problem Set 09

#Q6: Distance from top beam edge to centroid of flexural steel, d

DATASET: 1 -2- -3-

Span of slab	14 FT
Span of beam	23 FT
Thickness of slab	9 IN
section width, b	10 IN
section height, h	18 IN
max. aggrigate size	0.75 IN
bar size number	8
stirrup bar size number	4
concrete cover	1.5 IN
concrete ultimate strength, f'c	5500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	55 PSF



$$D_c = concrete\ cover + D_{Stirrup} + \frac{D_b}{2}$$
$$= 1.5 + 4 \times \frac{1}{8} + 8 \times \frac{1}{8} \times \frac{1}{2} = \mathbf{2.5\ IN}$$

$$D = h - D_c = 18 - 2.5 = \mathbf{15.5\ IN}$$

Problem Set 09

#Q7: The final calculated area of steel required, As,re

Trial 1

$$A_s = \frac{M_u}{\varphi f_y\left(d - \frac{a}{2}\right)} = \frac{M_u}{\varphi f_y(\mathbf{0.9}\ d)} = \frac{118.09\ K - FT \times \frac{12\ IN}{1FT}}{0.9 \times 60\ KIPS \times 0.9 \times 15.5} = \mathbf{1.88\ IN^2}$$

for beams

$$a = \frac{A_s f_y}{0.85\ f'_c\ b} = \frac{1.88 \times 60}{0.85 \times 6 \times 10} = \mathbf{2.21}$$

Trial 2

$$A_s = \frac{M_u}{\varphi f_y\left(d - \frac{a}{2}\right)} = \frac{118.09\ K - FT \times \frac{12\ IN}{1FT}}{0.9 \times 60\ KIPS \times (15.5 - \frac{2.21}{2})} = 1.82\ IN^2$$

$\mathbf{Check: 1.88 \times \%2 = 0.0376} \rightarrow$ ***Fail***

Problem Set 09

#Q7: The final calculated area of steel required, As,re

Trial 3

$$A_s = \frac{M_u}{\varphi f_y\left(d - \frac{a}{2}\right)} = \frac{M_u}{\varphi f_y(0.92\, d)} = \frac{118.09\ K - FT\ \times \frac{12\ IN}{1FT}}{0.9 \times 60\ KIPS\ \times 0.92\ \times 15.5} = \mathbf{1.84\ IN^2}$$

for beams

$$a = \frac{A_s f_y}{0.85\, f'_c\, b} = \frac{1.88\ \times 60}{0.85\ \times 6 \times 10} = \mathbf{2.16}$$

Trial 4

$$A_s = \frac{M_u}{\varphi f_y\left(d - \frac{a}{2}\right)} = \frac{118.09\ K - FT\ \times \frac{12\ IN}{1FT}}{0.9 \times 60\ KIPS\ \times (15.5\ - \frac{2.16}{2})} = 1.82\ IN^2$$

$$\mathbf{Check: 1.84\ \times \%2 = 0.036\ \rightarrow\ Pass}$$

Problem Set 09

#Q8: Number of rebars used
#Q9: Actual, final area of flexural steel used, As,used

DATASET: 1 -2- -3-

Span of slab	14 FT
Span of beam	23 FT
Thickness of slab	9 IN
section width, b	10 IN
section height, h	18 IN
max. aggrigate size	0.75 IN
bar size number	8
stirrup bar size number	4
concrete cover	1.5 IN
concrete ultimate strength, f'c	5500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	55 PSF

$$\boldsymbol{Bar_{num}} = \frac{A_S}{Bar\ Area} = \frac{1.82}{0.79} = 2.3 \Rightarrow = 3 \quad (round\ to\ the\ first\ highest\ integer)$$

$$\boldsymbol{A_{S_{used}} = 3 \times (0.79) = 2.37\ IN^2}$$

ASTM STANDARD INCH-POUND REINFORCING BARS			
BAR SIZE DESIGNATION	NOMINAL DIMENSIONS		
	AREA (in²)	WEIGHT (lb/ft)	DIAMETER (in.)
#3	0.11	0.376	0.375
#4	0.20	0.668	0.500
#5	0.31	1.043	0.625
#6	0.44	1.502	0.750
#7	0.60	2.044	0.875
#8	0.79	2.670	1.000
#9	1.00	3.400	1.128
#10	1.27	4.303	1.270
#11	1.56	5.313	1.410
#14	2.25	7.65	1.693
#18	4.00	13.60	2.257

The current A615 specification covers bar sizes #14 and #18 in Grade 60, and bar sizes #11, #14 and #18 in Grade 75. The current A706 specification also covers bar sizes #14 and #18. Bar sizes #9 through #18 are not included in the A996 specification.

Problem Set 09

#Q10: Mimimum required area of steel, As,min (the greater of the 2 criteria)

DATASET: 1 -2- -3-

Span of slab	14 FT
Span of beam	23 FT
Thickness of slab	9 IN
section width, b	10 IN
section height, h	18 IN
max. aggrigate size	0.75 IN
bar size number	8
stirrup bar size number	4
concrete cover	1.5 IN
concrete ultimate strength, f'c	5500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	55 PSF

$$As_{min} = max \begin{cases} \dfrac{3\sqrt{f'_c}}{f_y}\, b.d = \dfrac{3\sqrt{5,500}}{60,000} \times 10 \times 15.5 = \mathbf{0.574}\ IN^2 \\ \dfrac{200}{F_y}\, b.d = \dfrac{200}{60,000} \times 10 \times 15.5 = 0.516\ IN^2 \end{cases}$$

Problem Set 09

#Q11: Depth of concrete stress block, a

#Q12: The factor beta_1

#Q13: Distance to Neutral Axis from top of beam, c

section width, b	10 IN
section height, h	18 IN
max. aggrigate size	0.75 IN
bar size number	8
stirrup bar size number	4
concrete cover	1.5 IN
concrete ultimate strength, f'c	5500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	55 PSF

$$\boldsymbol{a = \frac{A_s f_y}{0.85\, f'_c\, b}} = \frac{2.37\ (60{,}000)}{0.85\ (5500)\ (10)} = \mathbf{3.04\mathit{IN}}$$

$$\boldsymbol{\beta_1 = 0.85\ - 0.05\left(\frac{f'_c\ - 4000}{1000}\right) = 0.775}$$

$$\boldsymbol{c = \frac{a}{\beta_1}} = \frac{1.9}{0.775} = \mathbf{3.92\ \mathit{IN}}$$

Problem Set 09

#Q14: strain in flexural steel, epsilon_t
#Q15: strength reduction factor, phi
#Q16: tensile force in the flexural steel, T

section width, b	10 IN
section height, h	18 IN
max. aggrigate size	0.75 IN
bar size number	8
stirrup bar size number	4
concrete cover	1.5 IN
concrete ultimate strength, f'c	5500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	55 PSF

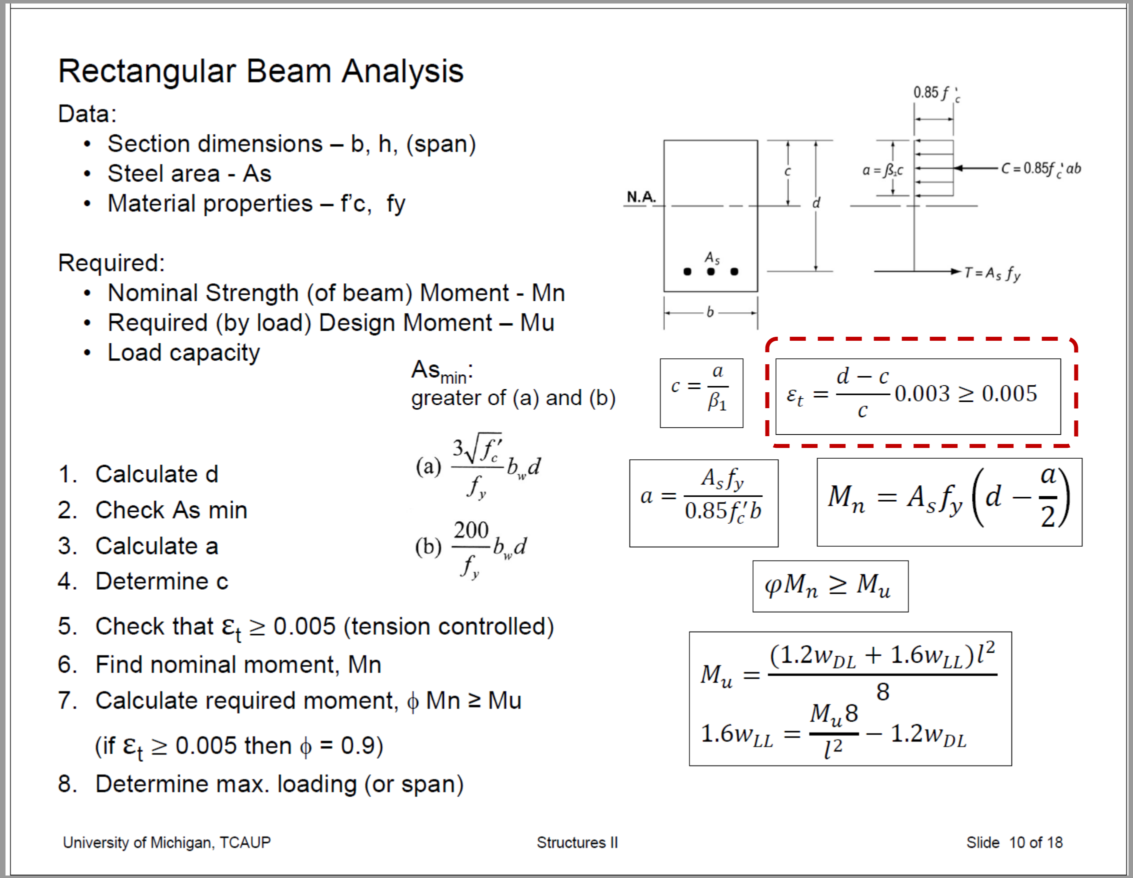
$$\boldsymbol{\varepsilon_t = \frac{d-c}{c}(0.003)} = \frac{15.5-3.92}{3.92}(0.003) = \mathbf{0.0088}$$

$$0.0088 > 0.004 \ \rightarrow ok$$

$$0.0088 > 0.005 \ \rightarrow tension\ controlled$$

$$\Rightarrow \ \boldsymbol{\emptyset = 0.9}$$

$$\boldsymbol{T = A_s f_y} = 2.37\,(60{,}000) = \frac{142{,}200}{1000} = \mathbf{142.2\ K}$$



Problem Set 09

#Q17: Nominal bending moment, Mn
#Q18: Factored bending resistance, phi Mn

section width, b	10 IN
section height, h	18 IN
max. aggrigate size	0.75 IN
bar size number	8
stirrup bar size number	4
concrete cover	1.5 IN
concrete ultimate strength, f'c	5500 PSI
steel yield strength, fy	60000 PSI
Floor Live Load	55 PSF

$$\boldsymbol{M_n = A_s f_y\left(d - \frac{a}{2}\right)} = 2.37\left(\frac{60000}{1000}\right)\left(15.5 - \frac{3.04}{2}\right) = \mathbf{1987.95\ K - IN}$$

$$\boldsymbol{\varphi M_n} = 0.9 \times 1987.95\ K - IN \times \frac{1\ FT}{12\ IN} = \boldsymbol{149.09\ K - FT}$$

Lab07

Structures II

Arch 324

Name 1 ____________________

Name 2 ____________________

Name 3 ____________________

Reinforcement Placement

Description

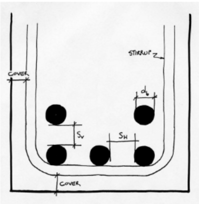
This project produces a graphic representation of the reinforcing layout of a concrete beam.

Goals

To determine bar diameters and horizontal spacing
To find the placement and dimensions of a shear stirrup.
To establish proper cover for reinforcement.
To draw all beam elements in the proper scale and location.

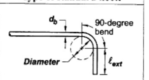
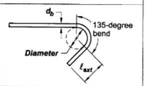
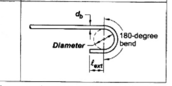
Procedure

1. For the example beam worked in class, determine the required spacing, s_v and s_h, for the bar size used.
2. For the given stirrup size determine the bend radius for a 90° bend.
3. Make a sketch showing the proper locations of bars and the stirrup including cover.
4. Draw and dimension the depth of the stress block, “a” and the distance to the N.A. from the top of the beam, “c”.
5. Dimension and label “d” and “d_c”.



Horizontal Spacing in Beams
ACI 25.2.1
1 inch
db
4/3 max aggregate

Table 25.3.2—Minimum inside bend diameters and standard hook geometry for stirrups, ties, and hoops

Type of standard hook	Bar size	Minimum inside bend diameter, in.	Straight extension[1] ℓ_{ext}, in.	Type of standard hook
90-degree hook	No. 3 through No. 5	$4d_b$	Greater of $6d_b$ and 3 in.	
	No. 6 through No. 8	$6d_b$	$12d_b$	
135-degree hook	No. 3 through No. 5	$4d_b$	Greater of $6d_b$ and 3 in.	
	No. 6 through No. 8	$6d_b$		
180-degree hook	No. 3 through No. 5	$4d_b$	Greater of $4d_b$ and 2.5 in.	
	No. 6 through No. 8	$6d_b$		

[1]A standard hook for stirrups, ties, and hoops includes the specific inside bend diameter and straight extension length. It shall be permitted to use a longer straight extension at the end of a hook. A longer extension shall not be considered to increase the anchorage capacity of the hook.

Due

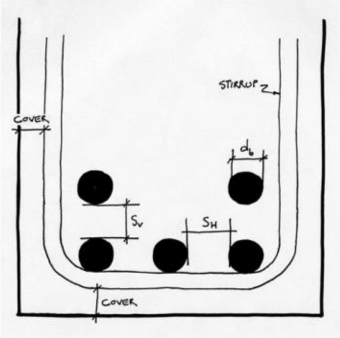
4 April 2021

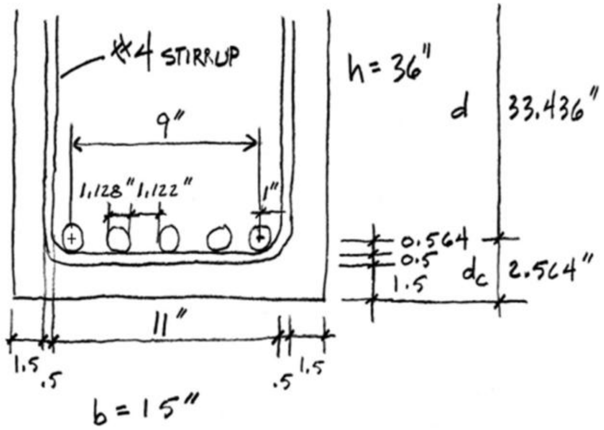
Rectangular Beam Design

7. Choose bars for A_s, determine spacing and cover, and revise d

CHOOSE BARS (SEE TABLE A.4)

TRY 5 x #9 BARS $A_s = 5.0$ in²





If bars do not fit in one layer, d is measured to the centroid of the pattern.

$$\bar{x} = \frac{\sum \mathbf{A} \times d_x}{\sum \mathbf{A}}$$

Table A.4 Areas of Groups of StandardBars (in.²)

Bar No.	Number of Bars 2	3	4	5	6	7	8	9	10	11	12	13	14
4	0.39	0.58	0.78	0.98	1.18	1.37	1.57	1.77	1.96	2.16	2.36	2.55	2.75
5	0.61	0.91	1.23	1.53	1.84	2.15	2.45	2.76	3.07	3.37	3.68	3.99	4.30
6	0.88	1.32	1.77	2.21	2.65	3.09	3.53	3.98	4.42	4.86	5.30	5.74	6.19
7	1.20	1.80	2.41	3.01	3.61	4.21	4.81	5.41	6.01	6.61	7.22	7.82	8.42
8	1.57	2.35	3.14	3.93	4.71	5.50	6.28	7.07	7.85	8.64	9.43	10.21	11.00
→ 9	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00
10	2.53	3.79	5.06	6.33	7.59	8.86	10.12	11.39	12.66	13.92	15.19	16.45	17.72
11	3.12	4.68	6.25	7.81	9.37	10.94	12.50	14.06	15.62	17.19	18.75	20.31	21.87
14	4.50	6.75	9.00	11.25	13.50	15.75	18.00	20.25	22.50	24.75	27.00	29.25	31.50
18	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00	40.00	44.00	48.00	52.00	56.00

Jack C McCormac, 1978
Design of Reinforced Concrete,

Lab07

Structures II

Arch 324

Name 1 ____________________

Name 2 ____________________

Name 3 ____________________

Reinforcement Placement

Description

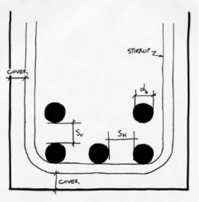
This project produces a graphic representation of the reinforcing layout of a concrete beam.

Goals

To determine bar diameters and horizontal spacing
To find the placement and dimensions of a shear stirrup.
To establish proper cover for reinforcement.
To draw all beam elements in the proper scale and location.

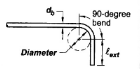
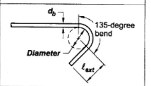
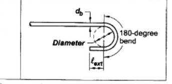
Procedure

1. For the example beam worked in class, determine the required spacing, s_v and s_h, for the bar size used.
2. For the given stirrup size determine the bend radius for a 90° bend.
3. Make a sketch showing the proper locations of bars and the stirrup including cover.
4. Draw and dimension the depth of the stress block, "a" and the distance to the N.A. from the top of the beam, "c".
5. Dimension and label "d" and "d_c".



Horizontal Spacing in Beams
ACI 25.2.1
1 inch
db
4/3 max aggregate

Table 25.3.2—Minimum inside bend diameters and standard hook geometry for stirrups, ties, and hoops

Type of standard hook	Bar size	Minimum inside bend diameter, in.	Straight extension[1] ℓ_{ext}, in.	Type of standard hook
90-degree hook	No. 3 through No. 5	$4d_b$	Greater of $6d_b$ and 3 in.	
	No. 6 through No. 8	$6d_b$	$12d_b$	
135-degree hook	No. 3 through No. 5	$4d_b$	Greater of $6d_b$ and 3 in.	
	No. 6 through No. 8	$6d_b$		
180-degree hook	No. 3 through No. 5	$4d_b$	Greater of $4d_b$ and 2.5 in.	
	No. 6 through No. 8	$6d_b$		

[1] A standard hook for stirrups, ties, and hoops includes the specific inside bend diameter and straight extension length. It shall be permitted to use a longer straight extension at the end of a hook. A longer extension shall not be considered to increase the anchorage capacity of the hook.

Due

4 April 2021

Reinforcing

Grade = Yield strength

- gr. 40 is 40 ksi
- gr. 60 is 60 ksi
- gr. 75 is 75 ksi

Size in 1/8 inch increments

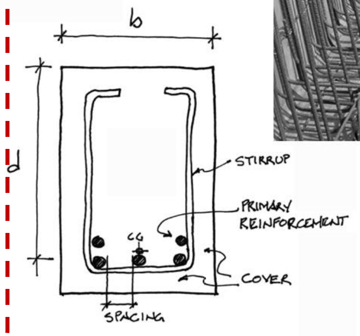
- #4 is ½ inch dia.
- #6 is ¾ inch dia.

Deformation Patterns

- add to bond with concrete

Minimum Spacing

- between bars (horizontal) the greatest of the 3 is the minimum
  - Bar diameter
  - 1"
  - 5/4 x max aggregate size
- between layers (vertical) 1"
- cover
  - 3" against soil
  - 1.5"-2" exterior
  - 3/4" interior



Reinforcement of Weidatalbrücke photo by Störfix

Lab07

Structures II
Arch 324

Name 1 ____________
Name 2 ____________
Name 3 ____________

Reinforcement Placement

Description
This project produces a graphic representation of the reinforcing layout of a concrete beam.

Goals
To determine bar diameters and horizontal spacing
To find the placement and dimensions of a shear stirrup.
To establish proper cover for reinforcement.
To draw all beam elements in the proper scale and location.

Procedure
1. For the example beam worked in class, determine the required spacing, s_v and s_h, for the bar size used.
2. For the given stirrup size determine the bend radius for a 90° bend.
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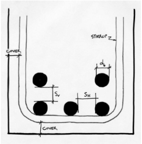
5. Dimension and label “d” and “d_c”.



Horizontal Spacing in Beams
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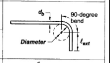
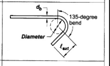
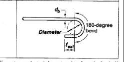
90-degree hook	No. 3 through No. 5	$4d_b$	Greater of $6d_b$ and 3 in.	
	No. 6 through No. 8	$6d_b$	$12d_b$	
135-degree hook	No. 3 through No. 5	$4d_b$	Greater of $6d_b$ and 3 in.	
	No. 6 through No. 8	$6d_b$		
180-degree hook	No. 3 through No. 5	$4d_b$	Greater of $4d_b$ and 2.5 in.	
	No. 6 through No. 8	$6d_b$		

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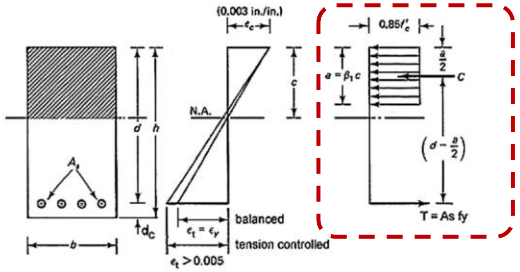
Due
4 April 2021

Flexure Equations

strain   ACI equivalent stress block



$$C = T$$

$$0.85f_c'ab = A_s f_y$$

solving for a,

$$a = \frac{A_s f_y}{0.85 f_c' b} = \frac{\rho f_y d}{0.85 f_c'}$$

$$\varepsilon_t = \frac{d - c}{c}(0.003) \qquad \rho = \frac{A_s}{bd}$$

$$M_n = T\left(d - \frac{a}{2}\right) = A_s f_y\left(d - \frac{a}{2}\right)$$

$$M_u = \phi M_n$$

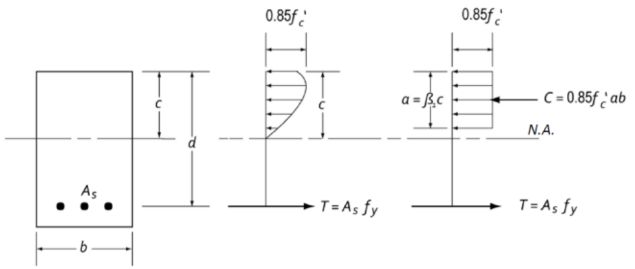
$$M_u = \phi M_n = \phi A_s f_y\left(d - \frac{a}{2}\right)$$

$$M_u = \phi A_s f_y d\left(1 - 0.59\frac{\rho f_y}{f_c'}\right)$$

ACI Stress Block

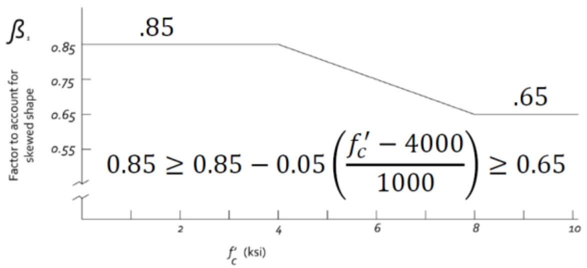
β_1 is a factor to account for the non-linear shape of the compression stress block.

$$a = \beta_1 c$$



psi

f'_c	β_1
0	0.85
1000	0.85
2000	0.85
3000	0.85
4000	0.85
5000	0.8
6000	0.75
7000	0.7
8000	0.65
9000	0.65
10000	0.65



$$0.85 \geq 0.85 - 0.05\left(\frac{f_c' - 4000}{1000}\right) \geq 0.65$$

Lab07

→ Group work instructions

Please form groups of 2 to 4 students.

Please do not forget to write all group members' names on both sheets.

Return the completed sheets to me at the end of the session.

Please ensure that you attend the recitation sessions.

If you are unable to attend a session, send me an email so that we can discuss how to proceed. *Email: arfazel@umich.edu*